Utilization of the Multilateral LMS Band for Fourth-Generation Mobile Communication Services

[A paper prepared for Telesaurus. Was further developed in other work.]

1 The Opportunity and the Challenge

The 902-928 MHz Location Monitoring and Services (LMS) band poses unique challenges — and unique opportunities — for *fourth generation* portable and mobile communication services. By itself, the LMS band has attributes that lends itself to high quality wireless services, including:

- a nationwide footprint, now consolidated over the 904-909.75 MHz and 919.75-928 MHz segments exclusively authorized for multilateral LMS (M-LMS) systems;
- high downlink (62 dBm aggregate EIRP) and uplink (52 dBm aggregate EIRP) radiated power limits, especially relative to incumbent users of the coincident 902-928 MHz band;
- reasonable out-of-band attenuation requirements (55 dB + P(dBW), compared to 43 dB + P(dBW) and 110 dB + P(dBW) for PCS and WCS bands, respectively);
- reasonable frequency stability requirements (2.5 ppm, e.g., ±2.3 kHz over the 902-928 MHz band);
- unrestricted limits antenna heights and modulation format, within power, out-of-band attenuation requirements, and frequency stability requirements described above;
- moderate-to-light restrictions on use of the band, in particular for delivery of mobile services; and
- subscriber location services, and services enabled by such location capability, as an integral (designed in) attribute of any larger mobility service.

In addition, placement of this band over the 902-928 MHz unlicensed (Part 15) band allows LMS systems to exploit many features shared (or added) by Part 15 services, including:

- greatly reduced (6-to-9 dB) pathloss and multipath dynamics relative to 2G PCS and emerging 3G mobility systems;
- greatly simplified interoperability with Part 15 operators and equipment, e.g., in nonmultilateral segments of the LMS band (902-904 MHz and 909.75-919.75 MHz), and in guard frequencies at the edge of M-LMS bands;
- access to low-cost subsystems, modules, and devices developed for the 902-928 MHz Part 15 band; and

Lastly, an LMS system may potentially exploit additional economies of scale due to its overlap/proximity to European GSM band (890-915 MHz, i.e., overlapping, on the GSM uplink; 935-960 MHz on the GSM downlink).

These attributes can provide the LMS service provider with strong advantages over conventional and emerging services employing 2G, 2.5G and 3G technologies. However, care must be taken to define both services and communications technology that recognize and account for the strong challenges posed in this band. In particular, the LMS service provider must account for the *co-channel interference*

(CCI) generated by Part 15 users as he designs his service and business model, and as he defines, builds, and deploys his communication airlink.

Part 15 CCI will affect the network capacity and quality of service (QoS) offered in the LMS band, as well as the airlink technology required to achieve specific capacity or QoS targets. This interference can be severe, especially in large urban and suburban markets where the LMS operator may be deploying equipment in the presence of aggressive Part 15 operators. More importantly, this interference can have time and frequency characteristics that preclude use of wideband airlink technologies such as CDMA, which is the leading technology candidate for next generation mobile communications in the PCS and 3G bands. In some cases, these leading communications formats can provide as little as 1/6 the performance of more advanced technologies that are better matched to the Part 15 interference spectrum.

This is illustrated in Figures 1 and 2, illustrating capacity of a point-to-point LMS link (Base and Mobile in a macrocellular LMS network) operating in the presence of an aggressively deployed Part 15 network. Figure 1 depicts the interference and LMS communications scenarios, and plots the interference spectrum observed at the LMS Base and Mobile under this communication scenario. Figure 2 plots the spectrum of the transmit signal needed to approach the Shannon (information theoretic) capacity of the LMS link under the uplink and downlink power constraints imposed in the LMS A-M block[1], and compares capacity of the optimal frequency-selective system, an equivalent wideband format (e.g., CDMA) that is not responsive to variation in the receive interference frequency response, and a CCI-free system, e.g., obtaining after excising Part 15 CCI from the receive data signal.

The Part 15 network is assumed to provide data communications between a collection of subscribers and a network of poletops, using an FHMA modulation format with 250 kHz separation between hop channels. The poletops are distributed over a randomly perturbed hexagonal grid, with 1 km separation between nominal poletop locations, while the subscribers are randomly distributed over the deployment area. The subscriber-to-poletop node density is assumed to be 10:1 (10 subscribers serviced by each poletop), with a 10:1 asymmetry in uplink/downlink traffic (10 times as much traffic flowing downstream as upstream). The power and (for poletops) heights of all Part 15 nodes are set be within the "Safe Harbor" limits for Part 15 devices.

As Figure 1 shows, the interference received at the Base and Mobile is both strong (20 dB above the noise floor at the Mobile, and 50 dB above the noise floor at the Base) and highly frequency selective. As a consequence, the optimal transmit waveform is also highly frequency selective, such that spectrally flat modulation formats, e.g., CDMA are particularly inefficient in this band. In Figure 2, for example, link capacity drops by a factor of 3 on the LMS downlink and a factor of 6 on the LMS uplink if the transmit spectrum is constrained to have a flat over the wideband segment. More importantly, the strong interference received at the LMS Base severely limits capacity in the absence of CCI excision, such that the optimal frequency selective system can only manage 52 kbps in this scenario. [2].

[1] 300 W ERP down, 30W ERP up on the 250 kHz FL segment, 30W ERP down or up on the 5.75 MHz wideband segment. This results in the well-known "water-filling" solution over channels with frequency-selective pathloss and/or background interference [DMT,IT]. An analogous approach is used in the *asymmetric digital subscriber line (ADSL)* data service.

[2] In fact, this capacity is computed for a system employing the 5.75 MHz LMS A-M wideband segment (which can be implemented using CDMA modulation formats) and the 250 kHz LMS A-M FL segment. The capacity of the wideband segment by itself is 40 kbps when used for downlink transmission and *1.4 kbps* when used for uplink transmission, i.e., CDMA would practically fail in this environment.

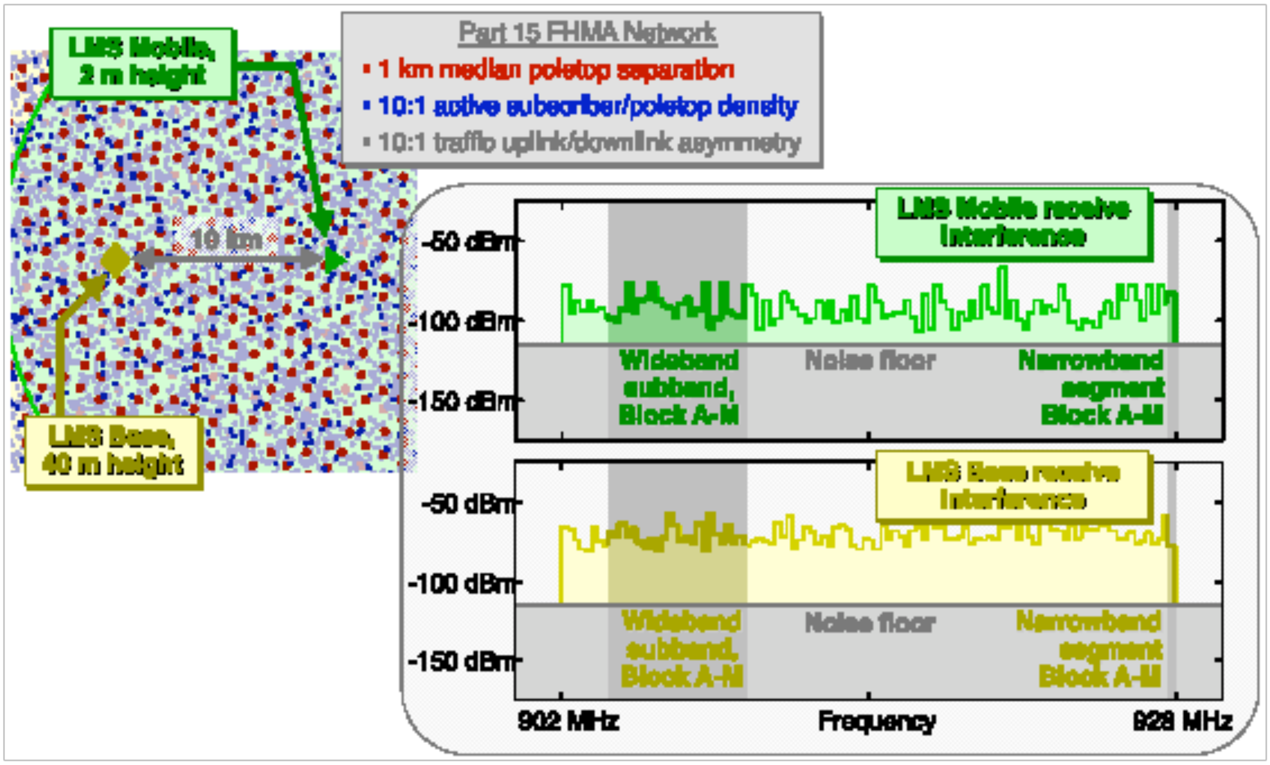

Figure 1: Receive Interference, Macrocellular M-LMS Network Scenario (Single LMS Link)

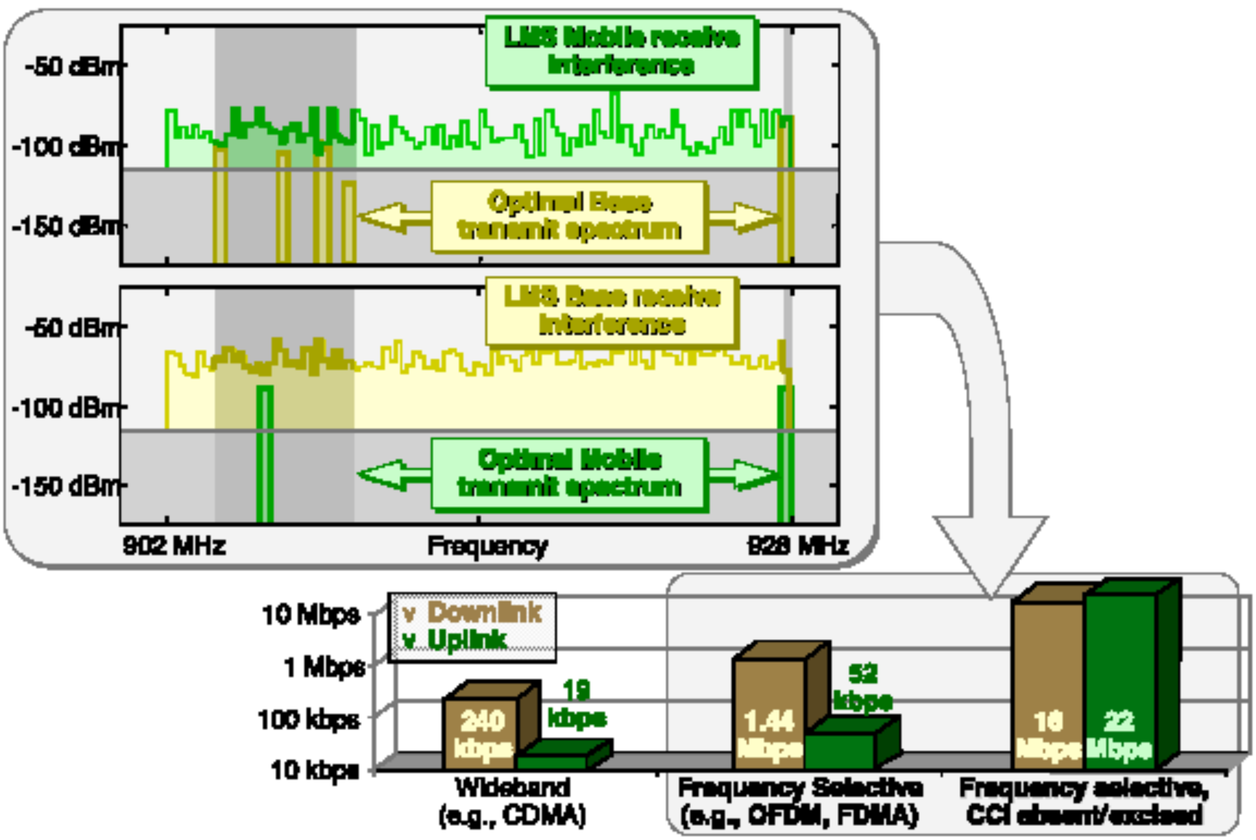

Figure 2: Receive Interference, Macrocellular M-LMS Network Scenario (Single LMS Link)

The effect of CCI is also dramatically illustrated in this Figure. In particular, downlink capacity is increased from 1.44 Mbps to 16 Mbps, and uplink capacity is increased from 52 kbps to 22 Mbps, if CCI can be removed from the Mobile and Base receive environments[3]. That is, CCI excision can increase capacity by a factor of 10 in on the system downlink, and by a factor of *400* on the system uplink!

Much higher link rates (and similar improvements over conventional wideband airlinks) can be seen in other LMS communication scenarios. This is illustrated in Figures 3 and 4, for an "LMS Microcell Network" scenario where a mobile is communicating with a poletop-based LMS Base over a 1 km range, and in Figures 5 and 6, for an "LMS Backhaul Scenario" (possible implemented as part of a microcell network) where two LMS Poletops are directly communicating over a 2 km range. In both cases, a 15 meter antenna height is assumed for the LMS poletop, consistent with wide area or roadside network deployments.

The lower poletop height greatly reduces the density and strength of interference observed at the poletop receivers, resulting in an uplink capacity of 12 Mbps and 49 Mbps for the microcell and backhaul scenarios, respectively, in the absence of CCI excision. Removal of CCI can improve uplink capacity to 79 Mbps and 122 Mbps, or by a factor of 6 and 3, respectively, in each network scenario. These capacities are a factor of 2 higher than capacity obtainable using spectrally flat waveforms.

This analysis motivates the use of *new* modulation techniques, growing from established (TDMA-FDMA 2G) or emerging (2.5G EDGE, OFDM) airlink technologies, along with sophisticated receive-site signal processing to excise Part 15 communication signals. In this regard, frequency-selective formats provide a much stronger basis for implementation of practical CCI mitigation techniques. Frequency-selective formats allow independent excision of CCI observed on each frequency channel, greatly reducing the degrees of freedom (e.g., independent communication antennas) required to perform such excision. Frequency-selective techniques are inherently better suited to mitigation (and in fact exploitation) of channel multipath; in particular, the narrower bandwidth of individual frequency channels greatly reduces "aperture blurring" effects (channel variability across frequency) that further limits the quality and excision performance of wideband systems. Lastly, the frequency-selective formats lend themselves to channelized DSP approaches that concentrate sophisticated signal processing at the DSP backend of the system where the strongest economies of scale can be obtained, and to *fast multitarget signal separation approaches* that can use this DSP to both boost the capacity of each Base in the network (users/Base), and greatly increase throughput and concentration in packet data systems.

Waveform enhancements are also warranted to support the full range of services desired in a competitive LMS-based communication system. In particular, high quality-of-service (QoS) offerings such as committed bit-rate (CBR) service for voice and video will require additional means (not found in 2G, 2.5G, or 3G airlinks) to combat the high time variability of Part 15 interferers. In addition, none of the 2G, 2.5G, or 3G standards developed to date have sufficient modes to allow the full range of interference excision required in the LMS band.

All of these factors provide compelling motivation for introduction of true fourth generation technology in the LMS band. If done right, the LMS band can not only provide a compelling service in its own right; it will also provide a testbed for the next generation of mobility technology and services.

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[3] Uplink and downlink differences are due to the different ERP limits on the FL segment (300W down, 30W up).

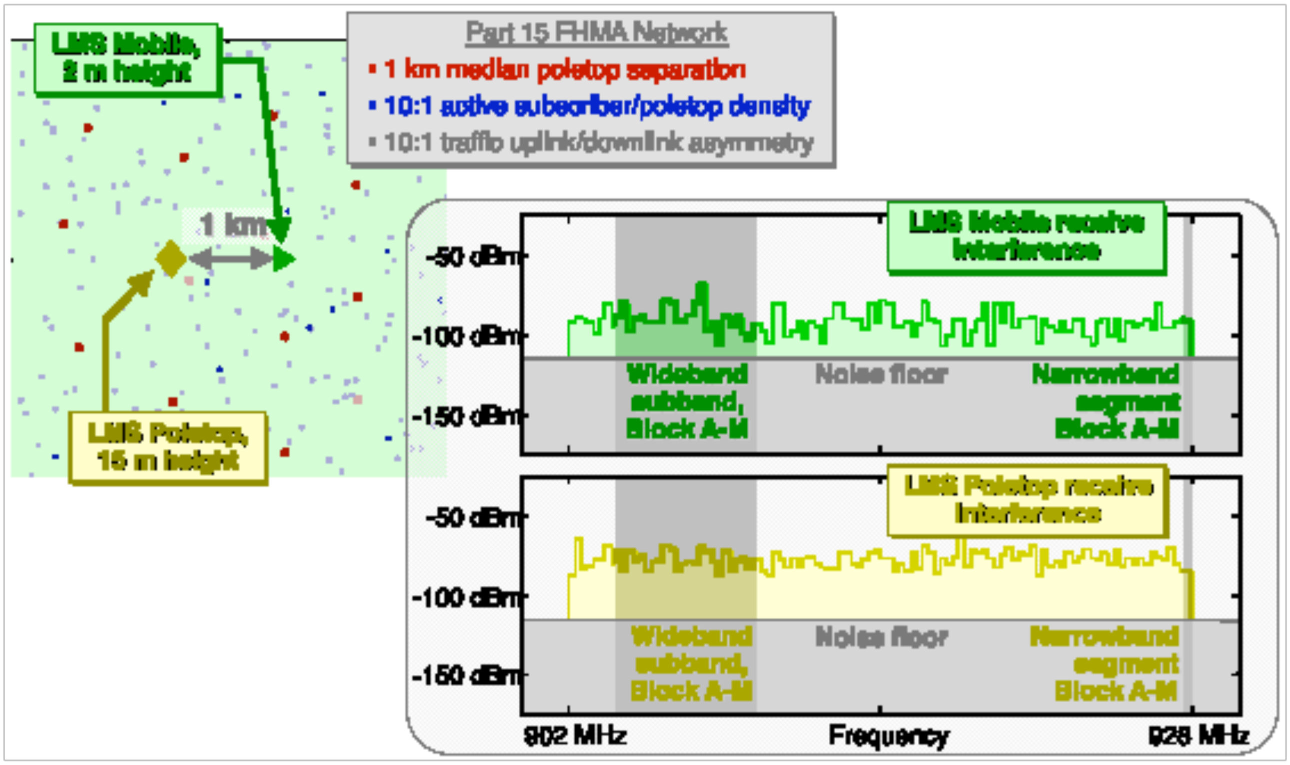

Figure 3: Receive Interference, Microcellular M-LMS Network Scenario (Single LMS Link)

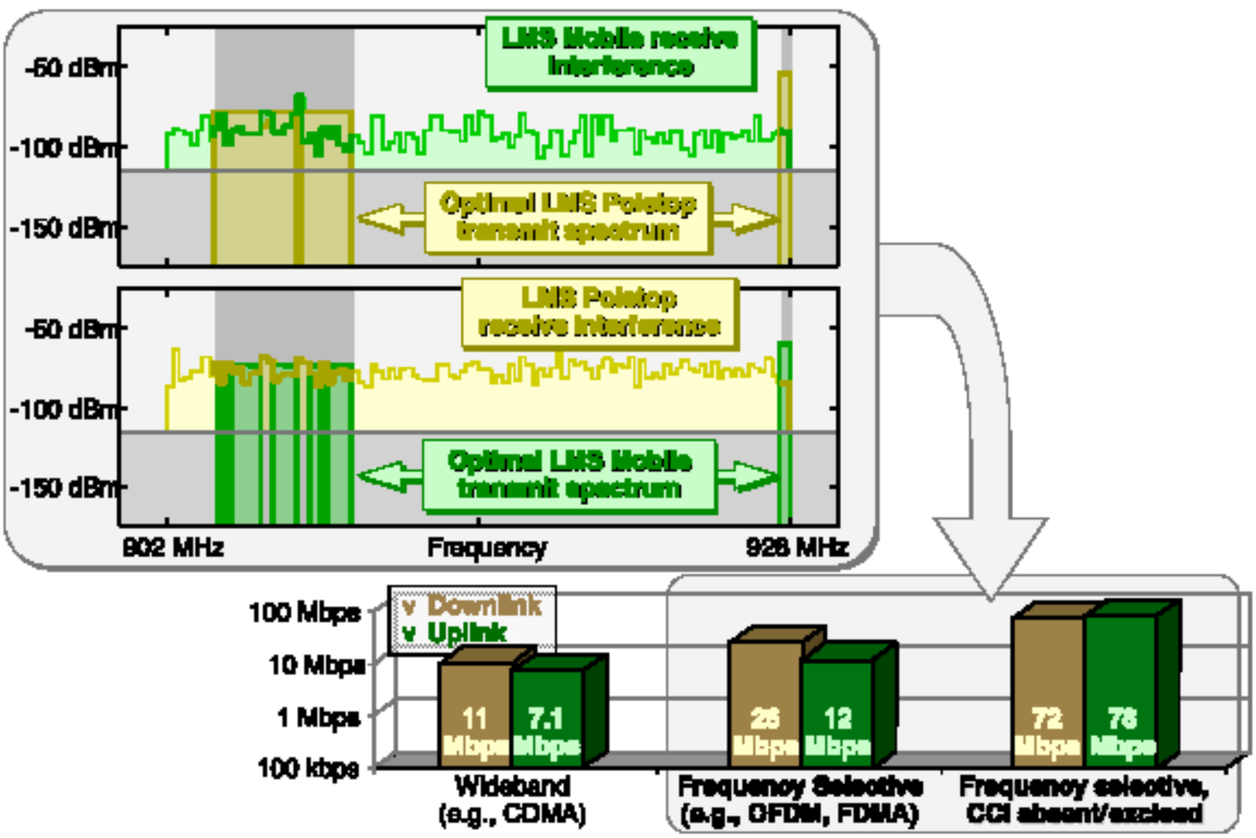

Figure 4: Receive Interference, Microcellular M-LMS Network Scenario (Single LMS Link)

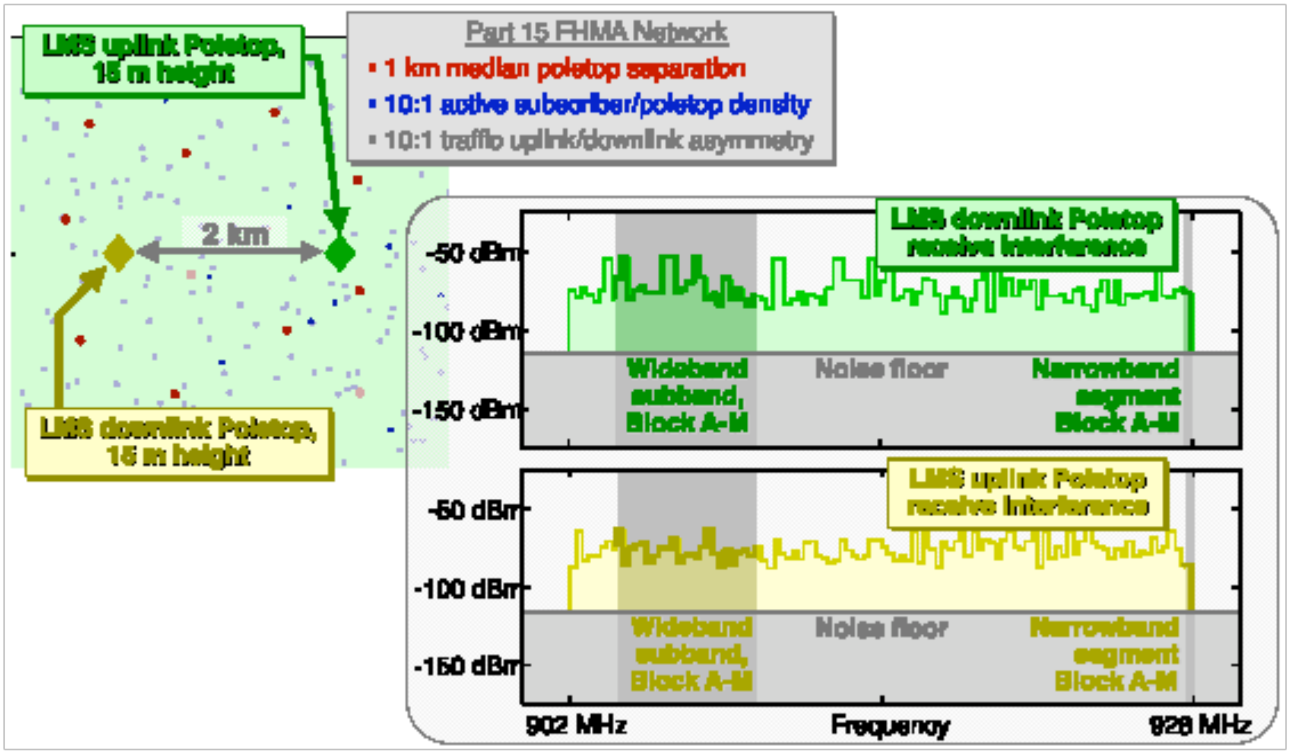

Figure 5: Receive Interference, Microcellular M-LMS Backhaul Link

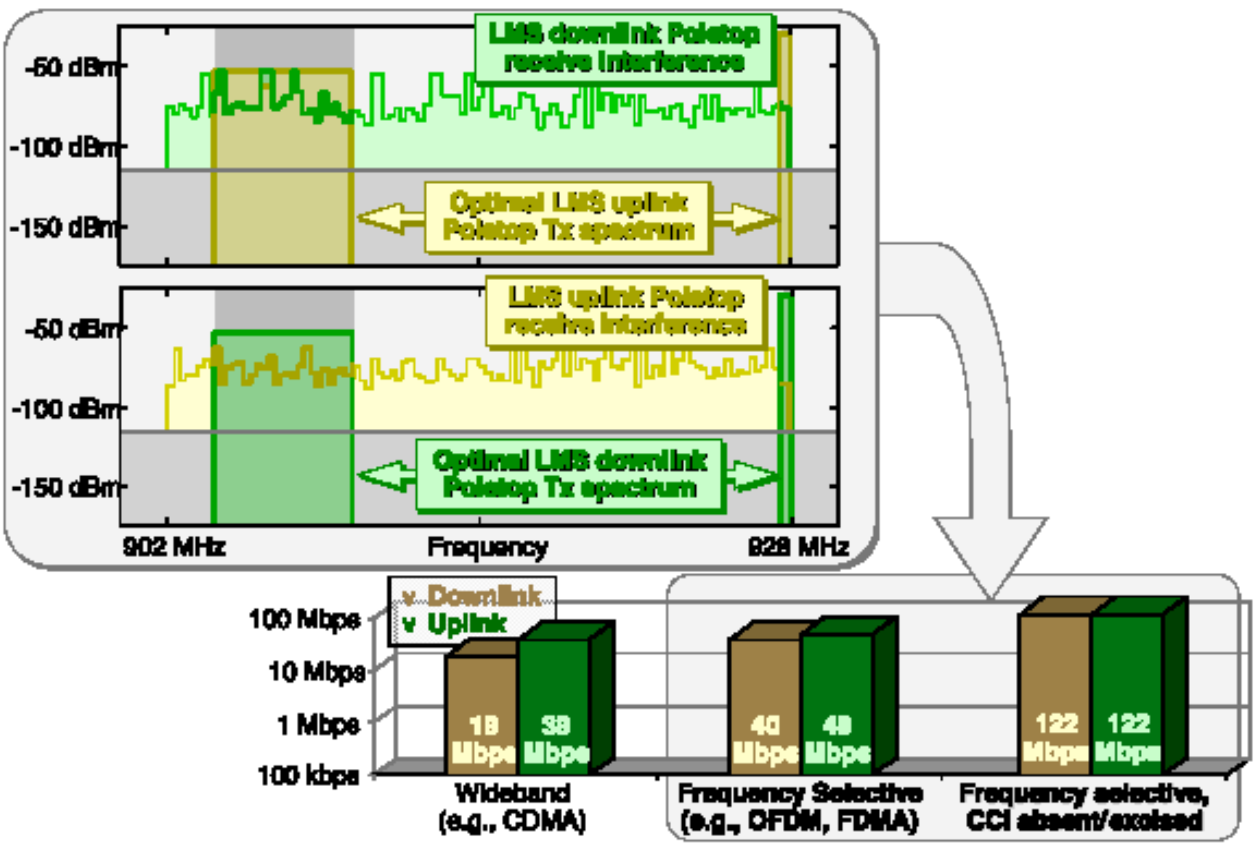

Figure 6: Receive Interference, Microcellular M-LMS Backhaul Link

2 Fourth Generation Technology Elements

Based on the analyses provided above, inherent attributes of the LMS band, and fundamental limitations of 2G-3G systems and technology, a preliminary fourth generation airlink is under development for this band. This airlink (will) possess the following technology elements.

- Time and frequency channelization, matched to the expected variability of Part 15 interference in the LMS band, and allowing exploitation of inherent benefits of narrowband modulation formats. Initial instantiations of this channelization may heavily exploit technology elements of 2G and 2.5G airlinks to minimize cost and/or time-to-market for the LMS offerings. Advanced (perhaps initial) instantiations of this technology will almost certainly use key RF elements of 2G, 2.5G, or (most likely) 3G airlinks to exploit established and emerging economies of scale for these airlinks.
- Baseband digital processing using software defined radio (SDR) methods, standards, and devices, to minimize time-to-market for the LMS system and concentrate innovation in the software-defined components of the system;
- Advanced (perhaps initial) means for instantiating time and frequency channelization, using patent pending variable-response multitone modulation that can flexibly modulate link capacity as a function of channel dynamics encountered by each link in the network, without compromising other elements of the overall communication airlink.
- GPS-based timing control at LMS Bases in the network, and robust, interference resistant synchronization methods to quickly acquire and track carrier and timing offset at mobiles in the network.
- Means for providing mobile-to-mobile service outside the network infrastructure.
- Time-division duplex (TDD) and/or TBD ad hoc single frequency networking to maximally exploit the spectrum provided in the M-LMS band.
- "High-IQ" smart antennas at Bases, microcell/roadside poletops, and high-end mobiles in the LMS network, implemented at digital baseband (i.e., over individual frequency channels and time slots), to excise strong Part 15 interference, boost network capacity, and maximize throughput and concentration of packet data users;
- Induced time and frequency redundancy to enable high quality of service applications, e.g., committed bit-rate for voice, video, and vehicle control;
- Mesh, ring, and bus network topologies, e.g., for backhaul and roadside systems, to maximize reliability, network capacity, and packet throughput through adaptive exploitation of route diversity.
- Locally enabled network optimization to continually maximize network capacity in star and nonstar cellular networks.

Initial analysis of this airlink indicates that it can deliver traffic payload at burst rates of 192 kbps full duplex (384 kbps aggregated) over 250 kHz or 320 kHz TDD links, scalable to 3 Mbps full duplex (6 Mbps aggregated) over 4 MHz of active bandwidth, e.g., within the A-M wideband segment. This capacity includes bandwidth set aside for link sync, control operations, error correction, and added filters to prevent interference with nearby nonmultilateral users (may be possible to use much more of this BW depending on specific ACI requirements of LMS band). This does *not* include inefficiency due to data fragment detection & retransmission; however, hooks have been added to allow fast (sub-millisecond if necessary) detection and acquisition of link packets, thus minimizing latency hit due to packet retransmissions. Features have also been added to allow interference excision via spatial, polarization, or time/frequency combining, and using fast, computationally efficient adaptation algorithms to maximize network and link capacity and throughput.

The baseline airlink also includes means for simply mitigating timing error of as much as 25 μs (allows implementation in microcells with 4-5 mile range), and combined carrier offset and Doppler of ± 5 kHz, or twice the carrier instability allowed under the LMS standard, in highly mobile users. The approach can also accomodate frequency and time division multiple access as well as spatial and polarization diversity, and to allow fast packet acquisition in random access data transfer applications.

Advantages of the approach are expected to be:

- data rates well in excess of rates to be provided in 2G, 2.5G, or 3G systems, particularly when combined with adaptive diversity exploitation means;
- ability to operate in the presence of strong, time and frequency variable Part 15 interference;
- ability to operate with large, time varying errors in carrier and clock sync;
- ability to pass small packets (expected to be the majority of traffic due to ITRS) quickly and without tieing up system resources;
- ability to overlay high-mobility and fixed/portable users on the same frequency channel — including ability to transition between high-mobility and fixed modes without handoff;
- ability to operate mobile-to-mobile services outside the network infrastructure;
- ability to scale up capacity at Base or mobiles using smart antennas or other diversity;
- ability to adapt power level and codec bits/symbol based on interference seen on each narrowband frequency channel (BTW, this is a fairly arbitrary channelization, and can be changed as circumstances dictate);
- ability to spread or hop over multiple time, frequency, and channel resources as interference varies in the channel.